X

Art. XXIII.—*On the Lateral Stability of the Victoria-street Bridge.*

By Professor Kernot.

[Read 16th November, 1882.]

Numerical Particulars Relative to the Victoria-Street Bridge.

Height of highest pier ...	86 feet from rock foundation. 74 feet from bed of river.
Breadth of base, extreme ...	19 feet.
Breadth to centres of cylinders	16 feet.
Weight of highest pier and corresponding portion of superstructure	105 tons.
Moment of stability, $105 \times \frac{18}{2}$ =	945 ft. tons.
Overturning wind pressure ...	69 lbs.
Moment of stability if provided with additional cylinders on the down-stream side only	On up-stream side, 2625 ft. tons. On down-stream side, 1574 ft. tons.
Overturning wind pressure ...	North, 192 lbs. South, 115 lbs.

The Victoria-street bridge occupies a peculiarly difficult site, one bank of the river being unusually high and the other comparatively low. To overcome this extreme difference of level it was necessary to adopt an unusually high bridge, and to place it upon a considerable slope. The funds available being very limited, it was not possible to adopt what may be called the heroic style of engineering, of which we unfortunately have so many examples in this country. The usual competition having been held a design was chosen, which happened to be the production of two young and comparatively inexperienced men; and the subsequent troubles have given rise to various remarks as to the undesirability of entrusting important designs to inexperienced persons. In reply to these remarks, it is to be pointed out that the choice of the design from a considerable number of competitors was made by experienced practical engineers, and the execution of the work supervised by a gentleman of high standing in the profession, and thus the responsibility was entirely removed from the shoulders of the original designers.

The engineer in charge of the execution of the work departed from the original design as far as the construction of the abutments was concerned, and a partial failure took place in this part of the structure. With the question of the desirability of this departure I do not propose at present to deal, but would merely say that the failure does not appear to me to be by any means as serious as it has been represented, or as similar movements in other structures with regard to which the public mind is at rest.

Before the failure took place the bridge was subjected to an unusually severe test by being traversed by the heavily-loaded drays carrying earth and rock from the cutting on the high side to the bank on the low side of the stream. Under this ordeal no sign of weakness appeared in the iron columns or girders.

On the occurrence of the partial failure of the abutments considerable alarm arose, and a Government engineer of high standing was called in to advise as to the remedy. This gentleman not only proposed a most complicated and costly reconstruction of the abutments, but went further, and condemned the rest of the bridge as unsafe under wind pressure, and insisted upon the width of the base of the taller piers being increased threefold. The arguments used in favour of this startling proposal were as follows:—

1. It was ascertained that on one occasion a wind pressure of 35 lbs. had been registered at the Observatory.

2. This pressure was multiplied by 3, giving 105 lbs. to the square foot as the extreme pressure the structure ought to be able to endure.

3. The moment of stability of the highest pier and corresponding portion of the superstructure was computed, and the ultimate overturning wind pressure determined as only 56 lbs. per square foot.

4. It was proposed to increase the width of the piers threefold in order to give the requisite resistance to wind pressure.

In conclusion, the case of the Tay Bridge was cited as an example confirming the preceding recommendation.

Let us consider the above investigation in detail.

1. The assumption that the bridge was liable to be exposed to a wind pressure of 35 lbs. per square foot is erroneous. No doubt such a pressure was once recorded at the Williamstown Observatory, which is excessively exposed. The bridge, however, is quite differently situated, and is protected on the north by a high range of hills. Whatever may have happened at Williamstown, the Victoria-street bridge is not likely to be exposed to a wind pressure of above 25 lbs., either from the north or the south.

2. The multiplying of the wind pressure by 3 involves a confusion between stability and strength. In a question of strength we need to allow a large factor of safety to cover the gradually weakening effect of a series of strains, each of which may be considerably less than what would be needed to cause immediate fracture. In the case of stability no such factor is needed, or as yet been proposed. If it takes a pressure of 35 lbs. to overturn a given object, a pressure of 34 lbs. may be allowed to act for ever, or may be exerted and removed a million times with perfect safety.

3. The calculation that makes the overturning wind-pressure of the structure only 56 lbs. per square foot is not a fair one. It arises from taking the distance between the centres of the cylinders (16 feet) as the effective base of the structure. As the cylinders are 3 feet in diameter the extreme width of base is 19 feet, and the effective width in view of overturning at least 18 instead of 16. Taking this into account, and calculating the weight and the area exposed to the wind with extreme care, I come to the conclusion the resistance to wind pressure of the highest pier is 69 lbs. per square foot, or 2·7 times the greatest possible wind pressure. Nor is this all. The adhesion of the concrete filling of the cylinders to the bed rock, the friction of the soil in which they are imbedded, and the assistance derived from the ends of the bridge through the medium of a wide and well-braced platform, constitute additional sources of stability, the effect of which cannot be exactly calculated, but which may at the most moderate estimate be taken as increasing the resistance to wind pressure to at least 100 lbs. per square foot. Thus

the bridge is seen to have most abundant stability against wind pressure, far beyond the practical requirements of the case.

As comparative examples confirming this view, it may be noted that ordinary chimneys have a resistance to wind pressure of from 20 to 50 lbs. per square foot, and that hundreds whose resistance is less than 30 have been standing for many years in positions far more exposed than the Victoria-street bridge. Further, that ordinary railway carriages have a resistance of in no case more than 55, and in many cases of less than 30 lbs., and yet have for many years traversed high embankments and viaducts in positions far more exposed than the structure in question, and that without accident.

In view of what has been above stated, it might appear unnecessary to refer to the proposed alteration. It is, however, a very singular fact that the recommendation greatly exceeds the requirements of the calculation upon which it is supposed to be based. Granting for the time being the 35 lbs. wind pressure as observed, and the desirability of providing a resistance of threefold the greatest force that can be brought to bear, all requirements may be complied with in a far simpler and cheaper way than that proposed. Instead of placing additional cylinders on both sides of the pier, as shown in Fig. 1, suppose we place them on the downstream, or south side, only, as in Fig. 2. We shall find that the overturning wind pressures become 192 lbs. per square foot on the north side and 115 lbs. on the south ; and as the greatest observed pressures are 35 and 23 lbs. respectively, it will be seen that in this way much greater stability might be obtained than the calculation requires.

A strong protest having been entered against the preceding proposals, a second engineer was called in, and he endorsed the recommendation to place additional cylinders on both up and down stream sides, but refrained from submitting any calculation, contenting himself with briefly expressing an opinion that it was desirable in view of floods.

This aspect of the question we must next proceed to examine, for it is manifestly conceivable that, though amply safe against wind, the structure might be dangerous when exposed to high floods. Particulars as to flood velocities and pressures are difficult to obtain, and consequently the only way to proceed is to institute comparisons with existing successful structures whose moment of stability does not exceed that of the bridge in question. On the Goulburn Valley railway, at Toolamba, is a very large timber bridge crossing the Goulburn. The highest pier of this structure is 69 feet high, and 27 feet wide at the base. It consists of redgum piles, driven through 7 feet of soft material, and then resting on the bed rock. At first sight the Toolamba pier seems much more stable than that at Victoria-street. But calculation tells a different tale. The former structure is composed of timber, a material which loses its weight entirely when immersed in water, while the latter is composed of iron and concrete, and will not lose more than one-third of its weight under similar conditions. Allowing for this circumstance, we find by a calculation, the details of which need not be given, that the moment of stability of the Toolamba bridge when the river is at high flood is barely half that of Victoria-street under similar conditions. As the Goulburn is a larger, deeper, and swifter river than the Yarra, and as the Toolamba bridge has already endured uninjured one very heavy flood, in which the floating timber formed a complete dam across the river, it follows that there are no grounds of apprehension at Victoria-street; and even if there were, additional cylinders on the down-stream side only would increase the resistance threefold, and render the bridge more than double as strong as the somewhat similar structures at Johnston-street, Collingwood, and Swan-street, Richmond. Thus the proposed alteration is seen to be as unnecessary from the flood as from the wind point of view.

The Victoria-street bridge question derives its importance from the fact that it is a point of contact and of conflict between two opposing schools of thought on engineering subjects. Those who belong to the old, or empirical, school, who hold that mathematical investigation is "mere theory," and that practice is the only guide, unanimously condemn it because it departs from the proportions to which they have been accustomed. Those who belong to the new and scientific school, who hold that the principles of statics are really and universally true, and constitute the essential basis of all sound engineering practice, approve of it because they find that its proportions throughout agree with the requirements of exact mathematical calculation; and the question before us to-night is, which of these opposing views is correct. If the recommendations of the two engineers who condemn the bridge are well founded, it will then follow that the principles of statics as laid down by all the authorities, and as taught in all our universities, are unreliable, and calculated to lead to serious errors when applied to engineering questions. If, on the other hand, the mathematicians are in the right, if the laws of statics are universally and practically true, then it follows that the engineers who have condemned the Victoria-street bridge are in the unfortunate position of being under a most serious misapprehension as to the correct mode of proceeding in the solution of the problems of engineering practice. Which of these two alternatives we are to adopt is the question I submit to the Royal Society to-night.